DESIGNING FOR METAL 3D PRINTING

PROTOLABS

HOW TO LEVERAGE ADDITIVE MANUFACTURING FOR METAL PARTS, DESIGN FOR THE TECHNOLOGY, AND USE POST-PROCESS FINISHING TO ENHANCE PART QUALITY

Additive manufacturing for metal prototypes and production parts is enabling design solutions to the world's most complex and challenging engineering problems. The ability to create one-off, complex parts is delivering value everywhere from satellite launch systems to medical instrumentation to manufacturing tooling.

While not a substitute for traditional metal manufacturing, direct metal laser sintering (DMLS) can be used to produce part designs that would be otherwise unachievable. Common design goals for metal 3D-printed parts include:

- Manufacturability of complex geometries
- Lightweighting
- Part Consolidation
- Mass Customization
- Topology optimization
- Cost reduction

But 3D printing a quality metal part isn't as simple as designing a CAD file and hitting the print button. Quality 3D-printed parts are a result of understanding how to design for the process, implementing commercial-grade materials, adhering to proper machine parameters, and taking advantage of several secondary processes.

PROCESS FLOW CHART

1 DESIGN
A thorough review of the design is conducted. Support structure placement and part orientation are determined.

2 BUILD
The material is loaded into the machine and the build begins. Starting with the first support structures, the metal powder is sintered one 20 or 30 micron layer at a time.

3 STRESS RELIEF
While still attached to the build plate, parts are placed inside a furnace to receive heat treatment based on the material's ASTM standard.

4 SUPPORT REMOVAL
Parts are machined off the build plate with wire EDM or a band saw. Support structures are removed from each part with hand tools.

5 FINISHING
When additional finishing is required, parts are sent to the CNC machine room for further processing to achieve tighter tolerances or improved surface finish on critical features.

6 HEAT TREATMENT
More advanced heat treatment processes are performed to enhance material properties.

7 INSPECTION
Parts are inspected to validate dimensional accuracy and ensure conformance with the supplied drawing.

8 SHIPMENT
Individual geometries are bagged by part number and shipped to customer.

BUILDING MATERIALS
CHOOSING THE RIGHT METAL FOR ADDITIVE MANUFACTURING

The metal powder used in DMLS is typically produced through an atomization process, which transforms raw metal material into 10 to 45 micron-sized spherical grains. The spherical grain structure is critical to achieving uniform powder layers during the build, resulting in reduced risk of porosity developing within the part.

STAINLESS STEEL
17-4 PH & 316L

ALUMINUM
AlSi10Mg

TITANIUM
Ti-6Al-4V

COBALT CHROME
CoCr

INCONEL
IN718

WHAT MATERIAL ATTRIBUTES DO YOU NEED?

STRENGTH
- Inconel
- Titanium
- Stainless Steel

LIGHTWEIGHT
- Aluminum
- Titanium

CORROSION RESISTANCE
- Stainless Steel
- Inconel
- Titanium
- Cobalt Chrome

STRENGTH-TO-WEIGHT
- Aluminum
- Titanium
- Cobalt Chrome

MATERIAL	ULTIMATE TENSILE STRENGTH	0.2% YIELD	ELONGATION	HARDNESS
Stainless Steel (17-4 PH)	190 ksi	170 ksi	8%	40-47 sHRC
Stainless Steel (316L)	70 ksi	25 ksi	30%	76.5 HRB to 25.5 HRC
Aluminum (AlSi10MG)	37.7 ksi	31.9 ksi	1%	47.2 HRB
Titanium (Ti-6Al-4V)	172 ksi	164 ksi	10%	40 HRC
Cobalt Chrome (CoCr)	130 ksi	75 ksi	20%	25 HRC
Inconel (IN718)	180 ksi	150 ksi	6-12%	35.5 HRB

BEFORE THE BUILD

DESIGN CONSIDERATIONS TO IMPROVE METAL PARTS

Let's take a look at some basic guidelines on how to design features on metal 3D-printed parts. Keep in mind that parts can be built in normal or high resolution. The two main factors to consider when selecting a resolution will be the part's overall volume and minimum feature size. Here are the part parameters at Protolabs:

	NORMAL RESOLUTION	HIGH RESOLUTION
Max. Part Size	9.6 in. x 9.6 in. x 10.6 in. (243.84mm x 243.84mm x 254mm)	3.5 in. x 3.5 in. x 2.6 in. (88.9mm x 88.9mm x 66.04mms)
Layer Thickness	0.00118 in. (30 microns)	0.00079 in. (20 microns)
Min. Feature Size	0.015 in. (0.381mm)	0.006 in. (0.1524mm)

DESIGNING FOR COST REDUCTION

- Design parts that can be self-supported to minimize the need for support structures and their removal
- Reduce material usage through topology optimization, hollowed-out features, and leveraging mesh and/or lattice structures

WALL THICKNESS

Thin walls below 0.040 in. (1mm) must maintain a wall height-to-thickness ratio of less than 40:1. Reinforcing thin walls with bracing, ribs, and gussets will reduce warpage during the build and maximize wall height.

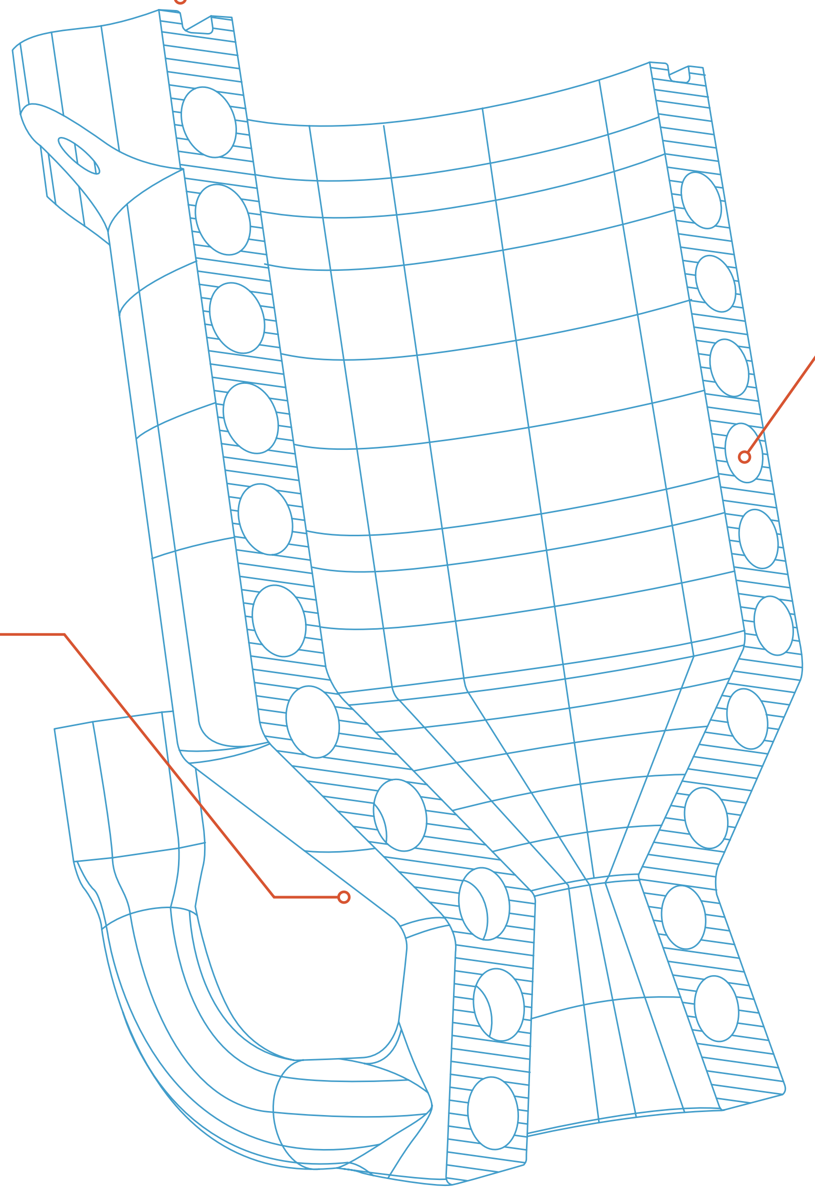
BRIDGES

The minimum allowable unsupported distance we recommend is 0.080 in. (2.032mm). Exceeding this recommended limit will result in poor quality on the down-facing surfaces and the feature will not be structurally sound.

SELF-SUPPORTING ANGLES

Angle self-supported features no less than 45 degrees from the build plate. For 316L stainless steel, the minimum self-supported angle is 55 degrees. As the angle of a self-supported feature decreases, the down-facing surface will become rougher and the risk of a build failing increases. Designing self-supported features will reduce costs by accelerating build speed and eliminating the need for support structure removal after the build.

ANATOMY OF A PART



LATTICE STRUCTURES

Designing parts with lattice or mesh structures can reduce material and weight for a part. Maintain an angle greater than 45 degrees from the build plate and bridge distances no larger than 0.08 in. (2mm). Minimum strut diameter is 0.015 in (0.38mm) for normal resolution and 0.01 in. (0.25mm) for high resolution.

CHANNELS

Channels can be any size if designed to be self-supporting such as a diamond or tear drop shape. If circular channels are required, maintaining a diameter no larger than 0.30 in. (8mm) is recommended to reduce roughness on down-facing surfaces.

TEXT

For best results, text should be inset at 0.015 in. (0.381mm) deep, 10-point font or larger, and bold if possible. Also consider the space between each digit—a minimum of 0.006 in. (0.1524mm) gap for high resolution and 0.012 in. (0.3048mm) for normal resolution is advisable.

DURING THE BUILD

CREATING PRECISION PARTS EVERY TIME

TOLERANCES

For well-designed parts, tolerances of ±0.003 in. (0.076mm) plus ±0.001 in./in. (0.001mm/mm) for each additional inch can typically be achieved. Note that tolerances may change depending on part geometry.

SUPPORT STRUCTURES

Support structures are necessary to connect parts to the build plate, hold features in place, and prevent warping. They also act as heat sinks during the production process by transferring heat from the part to the build plate. Designs with thick cross sections will require more support structures to combat the stress that builds up within the part and prevent the part from pulling itself off the build plate.

PART ORIENTATION

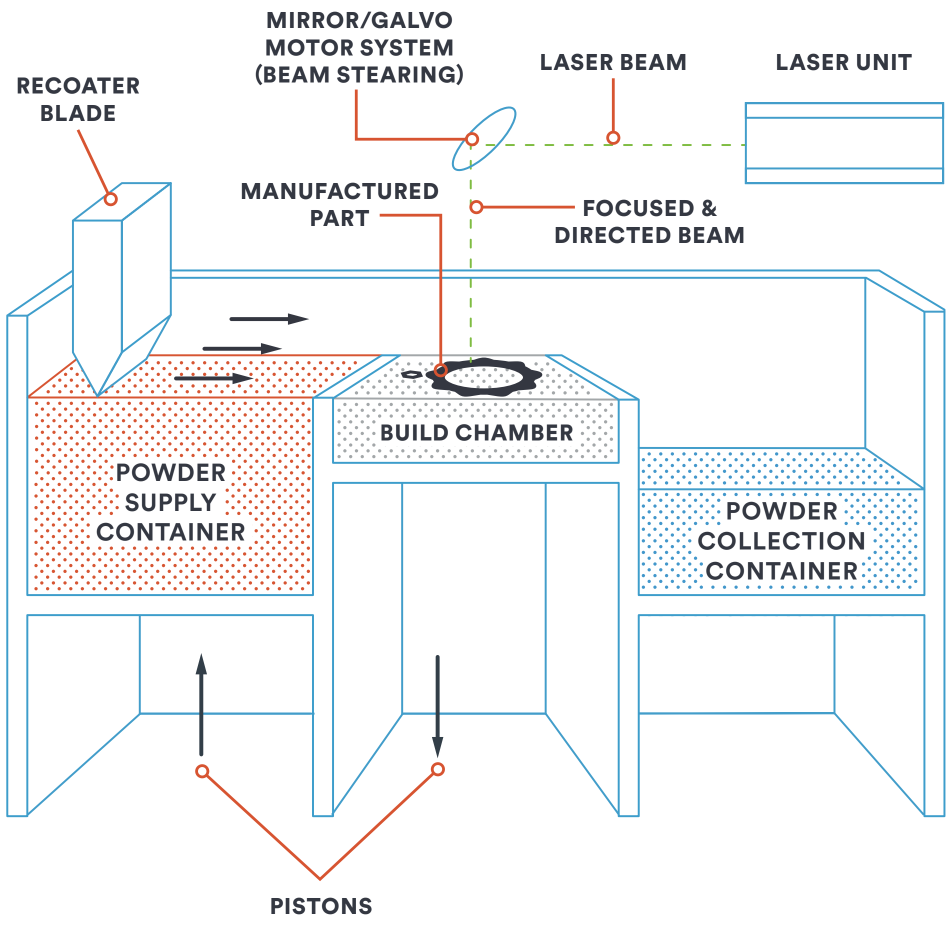
When determining the optimal build orientation, there are several factors to consider: minimizing support structures, accessibility to support structures for removal, warpage, build time, and surface finish quality.

SURFACE ROUGHNESS

Surface roughness will vary depending on the material, machine parameters, and part orientation. A typical metal 3D-printed part will have a surface finish of 200 to 400 µin Ra, which can be improved upon with machining or polishing after the build. The first, down-facing surface in a build will typically extend deeper than the nominal layer thickness, resulting in roughness.

ANATOMY OF A MACHINE

Once a thorough review of the part file is complete, part orientation and support structure placement are determined based on the application's requirements. The CAD model is then digitally sliced into 20 or 30 micron layers and sent to the DMLS machine for production.



IN PURSUIT OF PRECISION

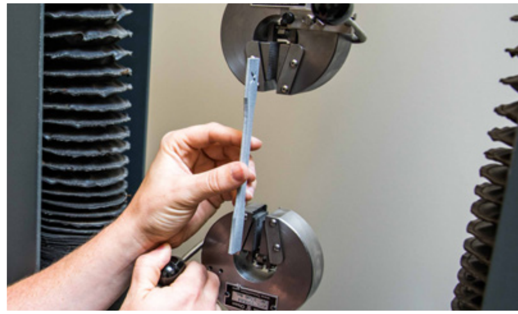
MACHINE PARAMETERS

Dialing in the correct machine parameters is critical to achieving quality parts in a variety of materials. For example, the machine's laser power must be carefully calibrated in order to melt powder particles of each layer consistently, but too much energy will lead to defects and less dense parts. Other parameters on the machine include scan speed, track pitch, spot size, and offset to original contour.

STATISTICAL PROCESS CONTROL (SPC)

SPC parts are included on every build to identify any trends in part quality:

- SPC parts used to validate tensile strength and dimensional accuracy
- Mechanical properties tested per ASTM E8 standard
- Density coupons tested per ASTM B311



HOW MATERIAL HANDLING AND POWDER ANALYSIS IMPROVE PART QUALITY

Protolabs takes the following steps to ensure materials meet quality requirements:

- Material is purchased per its ASTM standard
- Powder is tested to ensure material adheres to chemical composition defined by the respective ASTM document
- Particle size distribution is tested for reference and tracking
- A single lot of powder is used for every build and can be traced back to supplier

BEYOND THE BUILD

POST-PRODUCTION PROCESSING TO ENHANCE PARTS

With metal 3D printing technology, you're able to choose from several secondary processes like post-process machining, tapping, reaming, and heat treatments that produce end-use production parts. To ensure high-quality parts, we also offer process validation and inspection reporting, and our DMLS 3D printing process is ISO 9001-and AS9100D-certified.

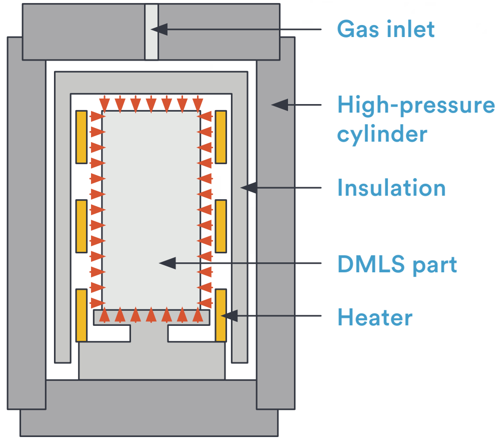
STANDARD SECONDARY PROCESSES

Standard Stress Relief: While still attached to the build plate, parts receive a standard heat treatment per ASTM 3301.

Support Structure Removal: After the build is complete, parts need to be removed from the build plate. Wire EDM is often used for this step. Support structures are removed in a variety of ways depending on part geometry and application requirements.

ADDITIONAL HEAT TREATMENTS

Hot Isostatic Pressing (HIP): This process combines high pressure and temperature to eliminate any potential of porosity within the part and reduce anisotropy. It also increases resistance to impact, wear, and abrasion. Typically HIP is used for aerospace components that will be under heavy loads.



Solution Annealing: The heat treatment process heats the workpiece above its recrystallization temperature and cools it down to relieve stresses and change microstructure. This is most commonly used for stainless steel parts as it reduces hardness and increases ductility.

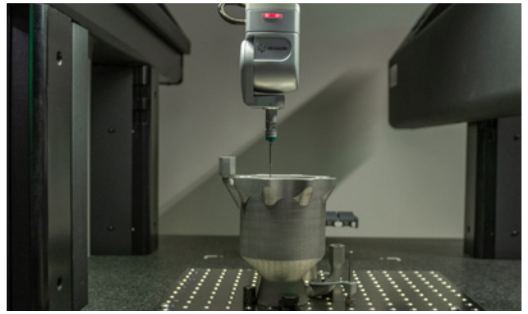
FINISHING

Once heat treatment is complete, parts will then be machined if required. With post-process machining tighter tolerances and improved surface roughness can be achieved. This is especially useful for parts with mating features.

Machining (Milling, EDM): Post-build CNC machining can be used to achieve tighter tolerances on features called out in the drawing. Typically, tolerances of +/- 0.001 in. Keep in mind that parts that will be machined need to be fixtured within a machine so curved or beveled surfaces can create challenges. In some instances, a sacrificial portion can be designed into the part to aid in fixturing and be removed after the process.

Tapping and Reaming: Parts with holes or threading can be tapped and reamed for accuracy.

Polishing: Using hand tools, polishing can achieve a near mirror finish on parts. If a surface requires polishing, be mindful that it is accessible.



INSPECTIONS

A variety of methods can be used to validate the part's geometry is in accordance with the supplied drawing.

Coordinate-Measuring Machine (CMM)

A CMM can be used to gather precision measurements to validate part features are within specified tolerances.

Computed Tomography (CT) Scanning

CT scanning provides a non-destructive means of validating internal features like channels and holes and ensures no unsintered powder or porosity is present within the part.

First Article Inspection (FAI)

First article inspection reporting in accordance with AS9102 is often used for parts that will be put in flight.